ELSEVIER
CrossMark
Available online at www.sciencedirect.com
ScienceDirect
Procedia Computer Science 32 (2014) 900 – 907
Procedia
Computer Science

The 2nd International Workshop on Body Area Sensor Networks (BASNet-2014)

A Novel Analytical Model for Provisioning QoS in Body Area Sensor Networks

Mohsin Iftikhar[a*], Iftikhar Ahmad[b]

[a]Department of Computer Science,[b]Department of Software Engineering,
College of Computer and Information Sciences, King Saud University 51178, Riyadh 11543, Saudi Arabia.

Abstract

Wireless Body Area Network (WBAN) has been an active area of research over the past few years due to its tremendous benefits particularly related to healthcare systems. The available research to evolve the QoS in WBAN is immature due to lack of sufficient methodology for modeling the behaviour of different kinds of traffic being generated from different kinds of events. It has been clearly demonstrated that traffic found in multimedia sensor nodes being used in WBAN is having bursty nature and cannot be modeled by using Poisson traffic distributions. However, most of the current available literature of traffic modeling related to Multimedia Wireless Sensor Networks (MWSNs) is based on Poisson distributions. To eliminate these kinds of performance evaluation limitations in MWSNs especially in time critical applications, this study proposes a novel analytical framework that relies on a traffic model resembling to an ON/OFF process. Proposed model exhibit self-similar behaviour and is capable to handle long range dependent traffic patterns. For providing enhanced QoS, proposed model deals with various traffic classes that has been judged in the current study through G/M/1 queuing system with a distinct scheduling strategy called as Low Latency Queuing (LLQ) to extract QoS performance metrics such as delay, queue length, throughput and packet loss rate (PLR). We also simulate the behaviour of traffic to further validate the proposed analytical framework.

Keywords: QoS; WMSNs; WBAN, G/M/1

*Corresponding author: Tel.:+966 543795002;fax: +966 1 4676993
Email: miftikhar@ksu.edu.sa

doi:10.1016/j.procs.2014.05.509

1. Introduction

Applications related to wireless sensor networks are amongst the most dynamic areas of technology development these days. Since from last decade, huge effort has been conducted in the area of WSNs. This scientific technology has evolved our lives, work, and interaction with the physical environment. WSNs can be considered as distributed computing workstations with various constraints, including minimum CPU speed, small memory size, low consumption of electric power, and bandwidth, where tiny size nodes communicate with each other in limited distances with low-power consumption. They are appropriate for a vast range of military, civil and other health related applications [21-24]. Nowadays, the obtainability of cheapest hardware such as CMOS cameras and microphones that are capable to ubiquitously record the multimedia content from the environment has fostered the growth of Wireless Multimedia Sensor Networks (WMSNs) [25], i.e., networks of wirelessly interrelated devices that permits retrieving of video and audio contents, still photos, and scalar sensor data. Wireless multimedia sensor networks has not only improved current sensor network systems such as tracking, home mechanization, and environmental screening, but they have also empowered many new applications such as: multimedia surveillance sensor networks, storage of related significant activities, traffic prevention, enforcement and control systems, enhanced health care delivery, environmental screening, person identification service and industrial development control etc. [25]. The vast set of applications imagined on WMSNs will have various requisites. Several above mentioned applications demand the sensor network paradigm to be reconsidered in view of the necessity for mechanisms to supply multimedia content with a specific range of Quality of Service (QoS).

Multimedia traffic, such as video, audio and still photo capturing can be categorized as distinct service classes and subjected to various schemes of scheduling, buffering and transmission. Sensor data may initiate from different set of events that have various degree of importance. Consequently, the content and nature of the sensed material also differs. As an example, that point outs the necessity for network level QoS; suppose, the task of bandwidth allocation for multimedia mobile medical calls, which comprise patients, sensing material, audio voice and image data. Unlike, the classic source-to-sink multi-hop linkage utilized by typical sensor networks, a distinctive architecture has been suggested in [26] in which single node forwards the sensed statistics to a cellular phone of 3G network or a dedicated information collecting entity. Hence, we imagined that WMSNs require to support and distinguish services for various classes of applications. Particularly, they need to facilitate differentiated service between time sensitive and delay-tolerant applications, and loss-tolerant and loss-intolerant applications.

Since the necessity to reduce the energy eating has driven vigorous research in sensor networks so far, appliances to proficiently deliver application level QoS, and to map these needs to network layer metrics such as delay and jitter, have not been mainly concerns in majority research on typical sensor networks. Because of vast set of applications of WSNS, researchers have been quite active in this field over the past years, but still there is poor research related to WSN traffic modelling. In addition, several traffic modelling work in the field of wireless sensor networks is assuming the source traffic either Constant Bit Rate (CBR) [27] or considering Poisson [28 -30]) data sources. However, the traffic load produced in wireless sensor networks deeply reliant on the application scenario which could be classified as *tracking of* bursty traffic which could not be modelled as either CBR or Poisson [31]. The presented work will facilitate a novel analytical framework for traffic modelling in WMSNs with accurate traffic assumptions (self-similar and long-range dependent). This novel modelling considering the *event-driven* and *periodic data production will* offer QoS satisfaction to various types of applications engaged in WMSNs relevant to their needs. Finally, it will explore a vast range of new applications related to WMSNs.

2. Related Work

The bulky implementation of MWSNs in safety and medical applications indicates the significance of WSNs in daily lives. To provide various set of treatments with specific level of QoS gaining in time sensitive applications is a hot issue nowadays. Today's WSN protocols [1-4] are reliant on end to end path prediction and path recovery. On the other hand many of other WSN protocols [5-7] are unreliable in terms of differentiating the multiple classes of network traffic under various constraints. The WSN and wireless ad-hoc networks routing protocols can be categorized in to two groups: (1) Flat routing and (2) hierarchical routing. The diversified problem with these two routing protocols is the non-accountability of QoS requirements for real time WSNs [1-3]. Many studies effort to predict maximum reachable throughput and latency in the capacity of Wireless ad-hoc networks [8-10]. The authors of several studies have described several queuing models under different queuing strategies like M/MMGI/1/K, G/G/1 to examine the performance of wireless ad-hoc networks [11-14]. Regrettably, the queuing examination conducted cannot be utilized to compromise guaranteed QoS in MWSNs due to two major reasons, (1) the traffic assumptions assumed are not realistic and (2) the results are just approximations. Various queues for various kinds of traffic under classifiers and schedulers have been discussed by the authors of study [15]. Both classes are fully capable to exchange bandwidth mutually. This scheme is based on cost and end to end metrics. The ultimate objective adopted in this work is to utilized minimum cost, and smaller delay for time sensitive data sets. In study [16] the authors assumed the problem of discovering the possibility of getting a lifetime threshold by the network which is alike to discover the complementary cumulative density function (ccdf) of the network lifetime by supposing that packet generation follows a Poisson distribution, an analytical expression for the (ccdf) of the lifetime is acquired. The outcomes of this work are attained for both multi-hop and single-hop WSNs and are tested with computer simulation. Again the results in [15-16] have been achieved by considering Poisson traffic input. In conjunction with this, queuing at MAC layer has been broadly discussed and many schemes with distinct levels of complexity persist. For example, of interest to multimedia applications is the development of strategies that permits a delay bound and thus promise smooth streaming of multimedia applications. A variant of weighted fair queuing has been announced in [17] to permit adjustments to be made to the energy-fidelity trade-off space. Given the bursty nature of voice and video data, queuing schemes are required to accommodate unexpected peaks, as well as drive under local channel errors. Spreading WFQ, the Wireless Packet Scheduling (WPS), discussed in [18], reports the concerns of latency and rate-sensitive packet flows thus declaring it reliable for multimedia contents. However, WPS considers that channel error is fully discoverable at any time its real employment shows marked deviations from the perfect case in terms of poorest-case complexity. Network Calculus theory [19], for deterministic queuing systems permits employment of service guarantees under traffic rules and deterministic scheduling. Presently, network calculus outcomes have been commonly derived for packet switched networks, and considered static topologies and fixed link capacity, which are obviously irrational hypothesis in sensor networks. There is minor work to date on network calculus correlated with sensor networks but we trust that spreading networks calculus results to WMSNs is thought-provoking but could be very auspicious research thrust, likely to create important advancements to facilitate QoS guarantees in multi-hop networks. Being inspired by the drawbacks of the present work, in this project, we aim to design novel analytical performance models for wireless sensor networks under real time traffic suppositions in order to facilitate differential and trusted QoS to multiple classes of traffic in MWSNs.

Additionally, there has been an excessive deal of research on employing mobility in WSNs to provide surveillance and reconnaissance in a eclectic deployment area. Further, it has been reported that sensor node mobility together with spatial correlation of the selected phenomenon creates new dynamics to the network traffic. These dynamics are good initiative of long range dependent (LRD) traffic, which imposes fundamentally unalike traffic modelling rather to traditional (Markovian) traffic. It has also been described obviously that the ratio of traffic burstiness, which is characterized by Hurst parameter, has an intimate link with the mobility variability and the ratio of spatial correlation [20]. Hence, we can predict, that appropriate traffic modelling in terms of providing differential QoS to various types of applications in the presence of asymmetric data traffic with various sizes and data rates in MWSNs is quite needy. We also discussed that communication protocols for sensor networks necessarily be supplied real time assurance and finally to facilitate guaranteed service with specified level of QoS, these protocols must be definitely designed with real time guarantees in mind. To get the detailed overview regarding the traffic modelling in wireless sensor networks that has been conducted particularly in recent years, we refer the readers to [38-40]. Moreover, these works also highlight the importance of considering the bursty nature of traffic in wireless sensor networks. The authors in [38-40] have also explained in detail that On/Off model is a very suitable candidate particularly for source traffic modelling in WSNs. Since, most of the traffic generated in WSNs in either even driven or application driven. These kinds of applications generate self-similar and long-range dependent traffic which can never be modelled by traditional Poisson models. In the current proposal, we have also selected a traffic model [33] that is very similar to on/off process and can be the most suitable candidate for source traffic modelling in WSNs. The considered model is almost second order self-similar and it has lot of attractive features which makes it a perfect candidate to be considered for source traffic modelling in WSNs. Also, we refer the readers to [41-45] to get an overview of some of the recent work that has been conducted in the area of WBAN. The current work can also play an important role for modelling the traffic being generated by different kinds of applications in WBANs. We would also like to refer the interesting readers to [35-37] to get an overview about QoS, queuing theory and polling systems (multiple queues, single server systems).

3. Proposed Analytical Framework

We have exploited G/M/1 queuing system to develop this analytical framework. In the analytical framework, we build the Markov chain and also extract the closed form expressions for different types of QoS classes for the sensor node of WBAN. We make some assumptions for the sensor node being deployed in WBAN. We assume that there are three kinds of traffic coming to the sensor node, the first one is the critical traffic (having the highest priority), second one is streaming traffic and the third one is non-critical traffic. A model of three queues based on G/M/1 has been considered. Since there is three type of traffic so we assume the service time distribution for these three types have rate μ_1, μ_2 and μ_3.

3.1. Markov Chain Transition Probabilities for Low Latency Queuing (LLQ) Model

We consider a model of three queues (one priority queue and two non-priority queues) based on G/M/1 by considering three different classes of self-similar traffic input. We analyze the system using LLQ as the scheduling discipline (the scheduler can serve non-priority queues only if there is no packet waiting in priority queue; further the scheduler serves non-priority queues in a round robin fashion according to specified reserved bandwidth by taking fixed number of bytes (packets) during each cycle; we specify the scheduler logic in such a way that the scheduler serves one packet from each non-priority queue during each cycle provided there is no packet waiting in priority queue). In the current study, we utilize the traffic model that has been discussed in [33]. It belongs to a specific class of self-similar traffic models freshly referred to as the telecom process in [34]. The model depicts the dynamics of packet creation while accounting for the scaling properties of the traffic in telecommunication networks. It resembles to an On/Off procedure. It is analytical (resolvable when served into queuing system), elastic (one model but many variants for different applications), implementable (less time consuming for simulation) and shows accuracy. Hence, the traffic model [33] is a suitable candidate to model the behaviour of various kind event driven bursty and long-range dependent traffic in MWSNs. We develop the finite Markov chain for LLQ scheduling discipline; extending the previous work on infinite capacity system. The formulation is based on observation of the queuing system at packet arrival instants. At these instants, the number in the system is the number of packets that the arriving packet sees in the queue plus the packet in service, if any, excluding the arriving packet itself. Let $\{X_n : n \geq 0\}$ denote the embedded Markov chain at the time of arrival instants. We define the state space as:

$$S = \{(i_1, i_2, i_3, a, s) : a \in \{a_1, a_2, a_3\}, s \in \{s_1, s_2, s_3, I\}, i_1, i_2, i_3 \in Z_+\}$$

We generate the transition probability matrix P of the Markov chain by specifying the transition probabilities from all the states in the states space i.e. non-idle states, states with empty queues and arrival at full queue. We only write down one transition in detail:

Transition from $(i_1, i_2, i_3, a_1, s_1) \rightarrow (j_1, j_2, j_3, a_2, s_2)$

We consider the case in which a transition occurs from an arrival of type 1 to an arrival of type 2 such that the first arrival has seen a type 1 packet in service, i_1 packets of type 1 (equivalently, total of queue 1 and the packet in service), i_2 packets of type 2 and i_3 packets of type 3 in the system. The transition occurs to j_1 packets of type 1, j_2 packets of type 2 and j_3 packets of type 3 in the system with a type 2 packet in service. Due to LLQ scheduling, an arrival of type 2 can see a type 2 packet in service in the next state only if all type 1 packets including the one that arrived in the previous state are exhausted during the interarrival time. That is why j_1 can take only the value 0 and exactly $i_1 + 1$ packets of type 1 are served. In contrast, the number of packets served from queue 2, say k, can be anywhere between 0 and $i_2 - 1$ as at least one type 2 packet is in the system, one being in service, when a new arrival occurs. Similarly, the number of packets served from queue 3 can be anywhere between 0 and i_3 due to RR scheduling between queue 2 and queue 3 and depending on the condition $(i_2 < i_3$ or $i_2 \geq i_3)$. The transition probabilities are: if $i_2 < i_3$:

$$P\{X_{n+1} = (0, i_2 - k, i_3 - k, a_2, s_2) \mid X_n = (i_1, i_2, i_3, a_1, s_1)\}$$

$$= \int_0^{\infty} \int_0^{t} \int_{t-x}^{\infty} f_{S_2}(s) f_{S_1^{i1+1} + S_2^k + S_3^k}(x) f_{T_{12}}(t)\, ds\, dx\, dt$$

Or if, $i_2 \geq i_3$

$$P\{X_{n+1} = (0, i_2 - k, 0, a_2, s_2) \mid X_n = (i_1, i_2, i_3, a_1, s_1)\}$$

$$= \int_0^{\infty} \int_0^{t} \int_{t-x}^{\infty} f_{S_2}(s) f_{S_1^{i1+1} + S_2^k + S_3^{i3}}(x) f_{T_{12}}(t)\, ds\, dx\, dt$$

Similarly we can write down all possible states.

3.2. Limiting Distribution and QoS Parameters for three queues LLQ Model

We can get the steady state distribution π as seen by an arrival by solving $\pi P = \pi$, where P is the transition matrix of the Markov chain. It is a known fact that the queue size in a sensor node is limited, hence Markov chain is finite and we can easily solve the steady state distribution. Our analysis is relying on arrival instances but it is also valid and logical for any G/M/1 queuing model, where the limiting distribution π at the arrival instances can be computed. First of all, we write down the queue length for three queues LLQ model. To the best of our knowledge, we have been the first to present the queue length results for G/M/1 queuing model in this paper for three queues LLQ model. In our earlier work on G/M/1 queuing system, we have just produced the results of waiting time and packet loss rate [31]. Queue length for class 1 packet will be simply the number of packets waiting in the system that must depart before this newly arrived type 1 packet. It can be written as follow:

$$E[QL_1] = \sum_{j_1=1}^{J_1-1} \sum_{j_2=0}^{J_2} \sum_{j_3=0}^{J_3} j_1 \pi(j_1, j_2, j_3, a_1, s_1) + \sum_{j_1=0}^{J_1-1} \sum_{j_2=1}^{J_2} \sum_{j_3=0}^{J_3} (j_1 + 1)\pi(j_1, j_2, j_3, a_1, s_2) +$$

$$\sum_{j_1=0}^{J_1-1} \sum_{j_2=0}^{J_2} \sum_{j_3=1}^{J_3} (j_1 + 1)\pi(j_1, j_2, j_3, a_1, s_3)$$

It clearly shows that the there are three possibilities when a new class 1 packet arrives.

(1) When a new class 1 packet arrives and finds a class 1 packet in service then its queue length is simply equal to the total number of class 1 packets waiting ahead of it in queue 1.
(2) When a class 1 packet comes and it finds a class 2 packet in service, then its queue length is equal to the number of packets (j1) waiting in queue 1 plus a type 2 packet, which is in service.
(3) When a class 1 packet comes and it finds a class 3 packet in service, then it's queue length is equal to the number of packets (j1) waiting in queue 1 plus a type 3 packet, which is in service.

Similarly, we can directly write down the queue length for class 2 and class 3 packets as follows. Since the scheduler serves one packet from queue 2/3 during each cycle, hence their queue length will be same:

$$E[QL_2] = \sum_{j_1=1}^{J_1} \sum_{j_2=0}^{J_2-1} \sum_{j_3=0}^{J_3} (j_1 + 2j_2)\pi(j_1, j_2, j_3, a_2, s_1) + \sum_{j_1=0}^{J_1} \sum_{j_2=1}^{J_2-1} \sum_{j_3=0}^{J_3} (j_1 + 2j_2)\pi(j_1, j_2, j_3, a_2, s_2) +$$

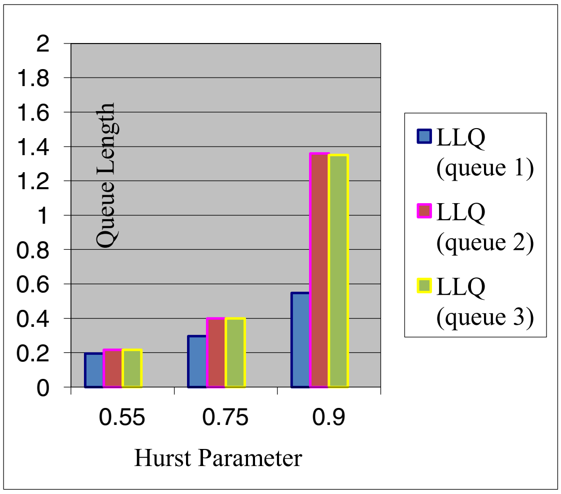
$$\sum_{j_1=0}^{J_1}\sum_{j_2=0}^{J_2-1}\sum_{j_3=1}^{J_3}(j_1+2j_2+1)\pi(j_1,j_2,j_3,a_2,s_3)+j_1E[QL_2]$$

Where the last term in the above equation $j_1E[QL_2]$ indicates that number of class 1 packets that arrive during the waiting time of newly arrived class 2 packet and because of high priority, those class 1 packets will depart before this newly arrived class 2 packet. Also, it is worth mentioning that the term $2j_2$ indicates the effect of round robin scheduling between queue 2 and queue 3, the scheduler will serve same number of packets from queue 3 as he takes from queue2. For other QoS parameters results such as delay and PLR, we refer the readers to our prior work [31] on G/M/1 queuing system.

4. Simulation Results

A comprehensive discrete-event simulator for queuing systems was built to understand and evaluate the QoS behaviour of self-similar traffic. The simulation engine is highly modular by design allowing free customization of the traffic generator and the scheduling logic. This allows for the ready evaluation of any scheduling discipline under any specific kind of input traffic. The key element for the scheduler logic is the Scheduler class. The design pattern allows any scheduling algorithm to be loosely coupled but easily integrated, overriding the existing program skeleton. LLQScheduler was actually implemented to analyze the corresponding QoS behaviour. The design pattern being introduced in [32] to simulate the bursty traffic has been followed in the current work. A traffic generator was also written. This generator may also be readily over-ridden by another traffic model. A number of other associated classes such as Simulation, Random No. Packet etc. were written to facilitate program function and accuracy.

The QoS results from the simulation studies with 95% confidence interval are presented. Fig. 1 and 2 shows queue length vs. Hurst parameter and delay vs. Hurst parameter for three queues LLQ model respectively. We can clearly observe that as soon as the Hurst parameter increases (i.e. burstiness of the traffic increases); there is an increase in QoS parameters particularly for low priority queues. We can also clearly observe the affect of round robin scheduling between queue 2 and queue 3 from the same QoS parameter values (delay and queue length).



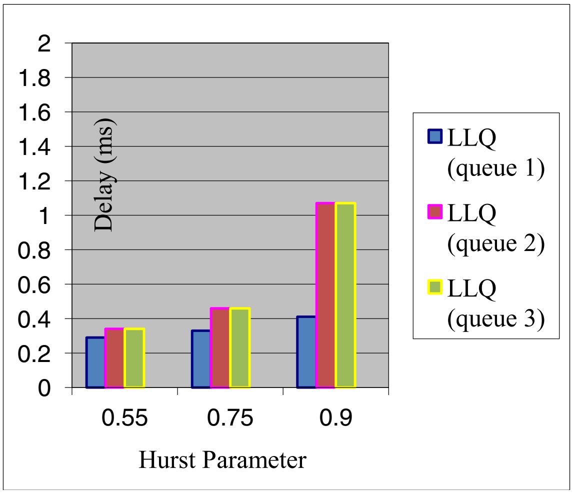


Fig. 1. Queue Lenght vs. Hurst Parameter

Fig. 2. Delay vs. Hurst Parameter

5. Conclusion and Future Work

In this paper, we have presented a three queues LLQ model to evaluate the behaviour of different kinds of traffic generated from different events in WBAN. We have developed the Markov chain and extracted the QoS parameters such as delay, queue length, bandwidth and PLR for different kinds of traffic. A discrete event simulator has been developed in C++ to simulate the traffic behaviour of corresponding traffic classes of WBAN. In the future, we aim to develop queuing models involving different types of polling schemes such as exhaustive, gated and limited service combined with traditional scheduling schemes. Because, if the traditional scheduling schemes are applied, it will not be possible to provide the required QoS to all kinds of traffic in WBAN. Hence, the main objective is to come up with novel and more sophisticated queuing models, which must be able to provide guaranteed QoS to all kinds of applications in WBAN according to their requirement.

Acknowledgement

This research work has been supported by Research Centre of College of Computer and Information Sciences at King Saud University, Riyadh, Saudi Arabia through grant no. RC131023.

References

1. T. Chen, J. Tsai, and M.Gerla, "QoS Routing Performance in Multihop Multimedia Wireless Networks," in *IEEE Sixth International Conference of Universal Personal Communications*, 1997, pp. 557–561.
2. R. Sivakumar, P. Sinha, and V. Bharghavan, "CEDAR: Core Extraction Distributed Ad Hoc Routing Algorithm," *IEEE Journal on Selected Areas of Communications,* vol. 17, pp. 1454–1465, 1999.
3. S. Chen and K. Nahrstedt, "Distributed Quality-of-Service Routing in Ad Hoc Networks," *IEEE Journal on Selected Areas of Communications,* vol. 17, pp. 1488–1505, 1999.
4. B. Hughesand and V. Cahill, "Achieving real time guarantees in mobile ad-hoc wireless networks," In *Proceedings of the Work-in-Progress session of the 24th IEEE Real-Time Systems Symposium*, Dec. 2003.
5. B. Deb, S. Bhatnagar, and B. Nath, "ReInForm: Reliable Information Forwarding Using Multiple Paths in Sensor Networks," in *Proceedings of IEEE LCN.*, pp. 406 – 415.
6. T. He, J. Stankovic, C. Lu, and T. Abdelzaher, "SPEED: A Stateless Protocol for Real-Time Communication in Sensor Networks," in *Proceedings of IEEE International Conference on Distributed Computing Systems*, 2003, pp. 46 – 55.
7. F. Stann and J. Heidemann, "RMST: Reliable Data Transport in Sensor Networks," in *Proceedings of IEEE International Workshop on Sensor Network Protocols and Applications*, 2003, pp. 102–112.
8. A. E. Gamal, J. Mammen, B. Prabhaker, and D. Shah, "Throughput-delay trade-off in wireless networks," in *IEEE INFOCOM*, March 2004.
9. J. Li, C. Blake, D. S. D. Couto, H. I. Lee, and R. Morris, "Capacity of ad hoc wireless networks," in *MobiCom 01, Pages61-69* New York, USA: ACM Press, 2001.
10. P. Gupta and P. R. Kumar, "Capacity of wireless networks," *IEEE Trans. on Information Theory,* pp. 388-404, March 2000.
11. G. zeng, H. Zhu, and I. Chlamtec, "A Novel Queueing model for 802.11 Wireless LANs," in *WNCG Wireless Network Symposium*, 2003.
12. O. Tickoo and B. Sikdar, "A Queueing model for finite load IEEE 802.11 random access MAC," in *IEEE ICC*, Paris, France, 2004.
13. M. Ozdemir and A. B. McDonald, "An M/MMG1/1/K queuing model for IEEE 802.11 ad hoc networks," in *Proceeding of PEWASUN' 05*, 2004, pp. 107-111.
14. N. Bisnik and A. Abouzeid, "Queuing Network Models for Delay Analysis of Multihop Wireless Ad Hoc Networks," in *The 2006 International Wireless Communications and Mobile Computing Conference (IWCMC 2006)* Vancouver, Canada:IEEE Communication Society and ACM, July, 2006.
15. K. Akkaya and M. Younis, "An Energy-Aware QoS Routing Protocol for Wireless Sensor Network," in *Proceedings of the 23 rd International Conference on Distributed Computing Systems Workshops (ICDCSW'03)*, 2003.
16. Moslem Noori and Masoud Ardakani "A Probability Model for Lifetime of Wireless Sensor Networks" http://arXiv.org/abs/0710.0020v1, 28 Sep 2007.
17. V. Raghunathan et al, "Energy efficient wireless packet scheduling and fair queueing", ACM transactions. Embedded Comput. Sys. 3 (1) 2004, 3-23.
18. S. Lu et al, "Fair scheduling in wireless packet networks', IEEE/ACM trans. Network, 7 (4) (1999), 473-489.
19. J. Y. L. Boudec, P. Thiran, "Network Calculus', LNCS, vol. 2050, Springer Verlag, New York, 2001.
20. P. Wang and I. F. Akyildiz "Spatial Correlation and Mobility Aware Traffic Modeling for Wireless Sensor Networks," to appear in Proc. IEEE GLOBECOM 2009, Honolulu, USA, November 2009.
21. Kahn, J. M., R. H. Katz, and K. S. J. Pister, "Next Century Challenges: Mobile Networking for Smart Dust," in *Proceedings of the Fifth Annual ACM/IEEE InternationalConference on Mobile Computing and Networking (MOBICOM '99)*, Seattle , Washington , USA, August 1999, pp. 271-278.
22. I. F. Akyildiz, W. Su, Y. Sankarasubramaiam, and E. Cayirci, "A Survey on Sensor Networks," in *IEEE Communication Magazine*. vol. 40, no 8, August 2002, pp. 102-114.

23. G. J. Pottie and W. J. Kaiser, "Wireless Integrated Network Sensors," *Communication of the ACM,* vol. 43, pp. 51-58, May 2000.
24. J. A. Stankovic, "Research Challenges for Wireless Sensor Networks," *SIGBED Review: Special Issue on Embedded Sensor Networks and Wireless Computing, 1(2),* July 2004.
25. I. F. Akyildiz et al, “A survey on wireless multimedia sensor networks”, Elsevier Journal of Computer Networks, 51 (2007), pp. 921-960.
26. F. Hu, S. Kumar, ‘Multimedia query with QoS consideration for wireless sensor networks in telemedicine”, in proc. of Society of Photo-Optical Instrumentation Engineers-Intl. Conference on Internet multimedia management systems, Orlando, FL, September, 2003
27. S. Cui, R. Madan, A. J. Goldsmith and S. Lall, ”Joint Routing, MAC, and Link Layer Optimization in Sensor Networks with Energy Constraints,” *Proceedings of IEEE ICC 2005*, Korea, May 2005.
28. Y. Ma and J. H. Aylor, ”System Lifetime Optimization for Heterogeneous Sensor Networks with a Hub-Spoke Topology,” *IEEE Transactions on Mobile Computing*, Vol. 3, No. 3, pp. 286-294, 2004.
29. M. Y Aalsalem, M. Iftikhar, J. Taheri and A. Y. Zomaya, “On the Provisioning of Guaranteed QoS in Wireless Sensor Networks through Limited Service Polling Models” The fifth IEEE and IFIP International Conference on wireless and Optical communications Networks (WOCN2008) Surabaya, East Java Indonesia, May 5, 6 and 7, 2008.
30. M. Y Aalsalem, M. Iftikhar, J. Taheri and A. Y. Zomaya, “ Providing QoS Guarantees to Multiple Classes of Traffic in Wireless Sensor Networks”, The sixth ACS/IEEE International Conference on Computer Systems and Applications (AICCSA-08), Doha, Qatar March 31 - April 4, 2008.
31. M. Iftikhar et al, “Towards the formation of comprehensive SLAs between heterogeneous wireless DiffServ domains” Springer journal of Telecommunications (2009), 42: 179-199.
32. D. Gross, J. Shortle, M. Fischer, D. Masi, “Difficulties in simulating queues with pareto service”, proc. of the 2002 winter simulation conference 2002.
33. M. Caglar, ‘A long-range dependant workload model for packet data traffic” Mathematics of Operations research, 29, pp. 92-105, 2004.
34. I. Kaj, “Limiting fractal random processes in heavy-tailed systems”, In Fractals in Engineering, New Trends in Theory and Applications, Eds.J. Levy-Lehel, E. Lutton, Springer-Verlag London, 2005, pp. 199-218
35. W. Odom and M. J. Cavanaugh, “IP Telephony Self-Study Cisco DQoS Exam Certification Guide”, Cisco Press, 2004, pp. 3-314
36. E. Glenbe, G. Pujolle and J. C. C. Nelson, “Introduction to Queueing Networks”, John Wiley and Sons, 1987.
37. H. Takagi, “Analysis of Polling Systems”, Research Reports and Notes, Computer System Series, The MIT Press, 1986.
38. Q. Wang, “Packet Traffic: A Good Data Source for Wireless Sensor Network Modeling and Anomaly Detection,” Proc. IEEE Network, 2011, pp. 15–21.
39. Q. Wang and T. Zhang, “Source Traffic Modeling in Wireless Sensor Networks for Target Tracking,” Proc. 5th ACM Int’l. Symp. Performance Evaluation of Wireless Ad Hoc, Sensor, and Ubiquitous Networks, Oct. 2008, pp. 96–100.
40. Q. Wang, “Traffic analysis, modeling and their applications in energy constrained wireless sensor networks”, PhD thesis, 2010, Midsweden university, Sweden
41. [41] B. Latré, B. Braem, I. Moerman, C. Blondia, and P. Demeester. "A survey on wireless body area networks." In *Wireless Networks*, vol. 17, pp. 1-18, January 2011.
42. M. R. Yuce. "Implementation of wireless body area networks for healthcare systems." In *Sensors and Actuators A: Physical*, vol. 162, pp. 116-129, June 2010.
43. M. A. Ameen, N. Ullah, M. S. Chowdhury, S. R. Islam, and K. Kwak. "A power efficient MAC protocol for wireless body area networks." In *EURASIP Journal on Wireless Communications and Networking*, vol. 33, p. 17, February 2012.
44. G. K. Ragesh and k. Baskaran. "An Overview of Applications, Standards and Challenges in Futuristic Wireless Body Area Networks." In *International Journal of Computer Science Issues (IJCSI),* vol. 9, pp. 180-186, January 2012.
45. E. Jovanov and A. Milenkovic. "Body Area Networks for Ubiquitous Healthcare Applications: Opportunities and Challenges." In *Journal of Medical Systems*, vol. 35, pp. 1245-1254, October 2011.